

MAPPING THE ZZ CETI INSTABILITY STRIP: DISCOVERY OF 6 NEW PULSATORS

A. GIANNINAS, P. BERGERON, AND G. FONTAINE

Département de Physique, Université de Montréal, C.P. 6128, Succ. Centre-Ville, Montréal, Québec, Canada, H3C 3J7.

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ABSTRACT

As part of an ongoing program to map better the empirical instability strip of pulsating ZZ Ceti white dwarfs, we present a brief progress report based on our last observing season. We discuss here high-speed photometric measurements for 6 new pulsators. These stars were selected on the basis of preliminary measurements of their effective temperature and surface gravity that placed them inside or near the known ZZ Ceti instability strip. We also report detection limits for a number of DA white dwarfs that showed no sign of variability. Finally, we revisit the ZZ Ceti star G232-38 for which we obtained improved high-speed photometry.

Subject headings: stars : oscillations – white dwarfs

1. MOTIVATION

The ZZ Ceti stars are pulsating white dwarfs whose optical spectra are dominated by hydrogen lines (DA stars). They are found in a very well defined region in the $T_{\text{eff}}\text{-log } g$ plane, known as the ZZ Ceti instability strip. They exhibit pulsation periods in the range 100-1400 s, corresponding to low degree gravity-mode oscillations. The detected pulsation modes have amplitudes that are found in the range from a few millimagnitudes in the low-amplitude pulsators to a fraction of a magnitude in the largest amplitude ones. The ZZ Ceti stars show some remarkable trends, although there are a few exceptions. For instance, the cooler pulsators tend to show longer periods and larger amplitudes. Also, for a given effective temperature, the observed periods tend to be longer for lower gravity objects.

Since the early 90's, our group in Montréal has been carrying out a systematic study aimed at defining the empirical boundaries of the ZZ Ceti instability strip. We use quantitative time-averaged optical spectroscopy to pin down the locations of candidate stars in the $T_{\text{eff}}\text{-log } g$ diagram, and we follow up on these candidates with “white light” fast photometry to determine if a target pulsates or not. The determination of these boundaries is essential if we are to understand better the ZZ Ceti phenomenon and to establish on a more quantitative footing the trends already alluded to above. The question of the purity of the instability strip (i.e., the absence of photometrically constant stars within) is also an important issue, and this for several reasons. First, a pure strip implies that the ZZ Ceti phenomenon is an evolutionary phase through which all DA white dwarfs must pass. It is then possible to apply what is gleaned from asteroseismological studies of these stars, such as information on their internal structure, to the entire class of DA white dwarfs. Second, knowing that the strip is pure allows us to predict the variability of a star simply through a measure of its atmospheric parameters, T_{eff} and $\log g$.

The paper of Bergeron et al. (1995) presented, for the first time, a complete and homogeneous picture of the ZZ Ceti stars in terms of their time-averaged properties. It was based on the sample of 22 pulsators known

at the time. In the meantime, we pursued our survey to improve statistics, and we reported several discoveries and new findings in a series of papers, the last of which is Gianninas et al. (2005) where references to our previous work can be found. One of the key results of Gianninas et al. (2005), based on our homogeneous spectroscopic sample of 39 pulsators and 121 constant stars, is the demonstration that the ZZ Ceti strip is indeed pure. Furthermore, that paper incorporated the first results of an extended ongoing survey whose primary aim is to define more accurately the empirical boundaries of the instability strip. That survey is based on spectroscopic measurements of a subsample of DA white dwarfs from the Catalog of Spectroscopically Identified White Dwarfs of McCook & Sion (1999). We thus obtain optical spectra for each star and then fit the Balmer line profiles using a grid of synthetic spectra generated from detailed model atmospheres. This allows us to accurately measure T_{eff} and $\log g$ for each star. It is then possible to identify white dwarfs whose atmospheric parameters place them near or within the ZZ Ceti instability strip. In this paper, we report on the latest results of this ongoing survey after the 2005-2006 observing season.

We note that with the recent releases of data sets from the SDSS, the number of known ZZ Ceti stars has grown in a spectacular way, by more than a factor of 2.5 (see, e.g., Mukadam et al. 2004b; Mullally et al. 2005; Kepler et al. 2005; Castanheira et al. 2006). The vast majority of the new pulsators, however, are significantly fainter than those previously known and, therefore, have a much less interesting asteroseismological potential. Moreover, the relatively low S/N ratio spectroscopic observations reached in the SDSS limits the usefulness of statistical studies based on them. Of particular interest here, Mukadam et al. (2004a) claimed that the ZZ Ceti instability strip contains several nonvariable stars on the basis of the SDSS sample of Mukadam et al. (2004b). We conclusively showed in Gianninas et al. (2005), however, that this incorrect result could be explained in terms of insufficient S/N ratio in the SDSS spectra. Thus, we believe that improvements in our empirical description of the ZZ Ceti instability strip necessarily rests on high S/N (> 80) time-averaged spectroscopy such as in the survey we are currently pursuing.

TABLE 1
JOURNAL OF OBSERVATIONS

WD	Name	Run	Date	Start Time	Total Number of
		Number	UT	UT	Data Points
0016–258	MCT 0016–2553	kit-013	2005 Oct 27	05:43	867
0036+312	G132-12	kit-005	2005 Oct 25	05:25	1042
		kit-017	2005 Oct 28	04:42	1348
		kit-009	2005 Oct 26	05:55	410
0136+768	GD 420	kit-002	2005 Oct 24	07:28	736
0145+234	MK 362	kit-010	2005 Oct 26	07:18	532
0302+621	GD 426	kit-003	2005 Oct 24	10:04	899
0344+073	KUV 03442+0719	kit-011	2005 Oct 26	09:07	1188
		kit-015	2005 Oct 27	11:25	366
		kit-006	2005 Oct 25	08:49	505
0347–137	GD 51	kit-014	2005 Oct 27	08:54	801
0416+701	GD 429	kit-007	2005 Oct 25	10:31	737
0741+248	LP 366-3	kit-021	2006 Mar 23	08:47	723
1150–153	EC 11507–1519	kit-018	2006 Mar 23	03:43	582
1211+320	CBS 54	kit-022	2006 Mar 23	11:11	439
1503–093	EC 15036–0918	kit-111	2005 May 01	13:42	328
1820+709	GD 530	cfh-119 ^a	2005 Aug 14	05:52	468
		kit-012	2005 Oct 27	02:21	1048
		kit-016	2005 Oct 28	01:54	918
2148+539	G232-38	kit-004	2005 Oct 25	02:04	1082
2148–291	MCT 2148–2911	cfh-117 ^a	2005 Aug 13	07:33	382
2311+552	GD 556	kit-001	2005 Oct 24	02:17	1724
2336–079	GD 1212	kit-008	2005 Oct 26	02:23	1083

^a Observed through a B-band filter.

Notes. – The sampling time is 10 s for all observations.

This limits the potential targets to relatively bright stars ($V < 17$), but as we are finding out as well as others (see, e.g., Silvotti et al. 2005; Voss et al. 2006), there are still bright ZZ Ceti pulsators to be discovered.

2. RESULTS

We proceeded to secure high-speed photometric measurements for those newly analyzed stars in our spectroscopic survey whose atmospheric parameters would place them inside or near the edges (blue and red) of the known ZZ Ceti instability domain. These follow-up observations were secured over the course of 3 observing runs in 2005 and 2006. In all, 6 of these stars turned out to be genuine pulsating DA white dwarfs: ZZ Ceti stars. A summary of our observations is presented in Table 1. MCT 2148–2911 was observed on 2005 August 13 with the 3.6 m Canada-France-Hawaii telescope equipped with LAPOUNE, the portable Montréal three-channel photometer. MCT 0016–2553, G132-12, KUV 03442+0719, and GD 1212 were observed during a 5 night run from 2005 October 23 to 27 at the Steward Observatory 2.3 m telescope, equipped once again with LAPOUNE. Finally, EC 11507–1519 was observed on 2006 March 22 at Steward Observatory with the same telescope and setup. Figure 1 displays the sky-subtracted, extinction-corrected light curves obtained for each star. The resulting Fourier (amplitude) spectra are shown in Figure 2.

Summarized in Table 2 are the data for the 6 new ZZ Ceti stars split into short and long period variables. We list the V magnitude as well as the amplitude and period of the dominant pulsation mode obtained from the corresponding Fourier spectra in Figure 2. In Table 3, we provide the data for the white dwarfs we found to be

TABLE 2
PHOTOMETRIC PARAMETERS OF NEW ZZ CETI WHITE DWARFS

WD	Name	V	Amplitude (%)	Dominant Period (s)
Short Period				
0036+312	G132-12	16.20	0.43	212.7
1150−153	EC 11507−1519	16.00	0.77	249.6
2148−291	MCT 2148−2911	16.10	1.26	260.8
Long Period				
0016−258	MCT 0016−2553	16.10	0.81	1152.4
0344+073	KUV 03442+0719	16.10	0.76	1384.9
2336−079	GD 1212	13.26	0.54	1160.7

photometrically constant. In addition to the apparent magnitude, we also indicate the limit to which no photometric variations were detected (in the 20–2000 s period range). This limit corresponds to three times the mean noise level of the Fourier transform in that period range. It is expressed as a percentage of the mean brightness of the star.

The atmospheric parameters for the 6 new ZZ Ceti stars and the 10 photometrically constant DA white dwarfs are reported in Table 4 together with the stellar masses and absolute visual magnitudes. Our theoretical framework and fitting technique are described at length in Gianninas et al. (2005) and references therein. To obtain proper time-averaged spectra for ZZ Ceti stars, it is necessary to set the exposure time long enough to cover several pulsation cycles. However, not knowing a priori that the stars listed in Table 2 would turn out

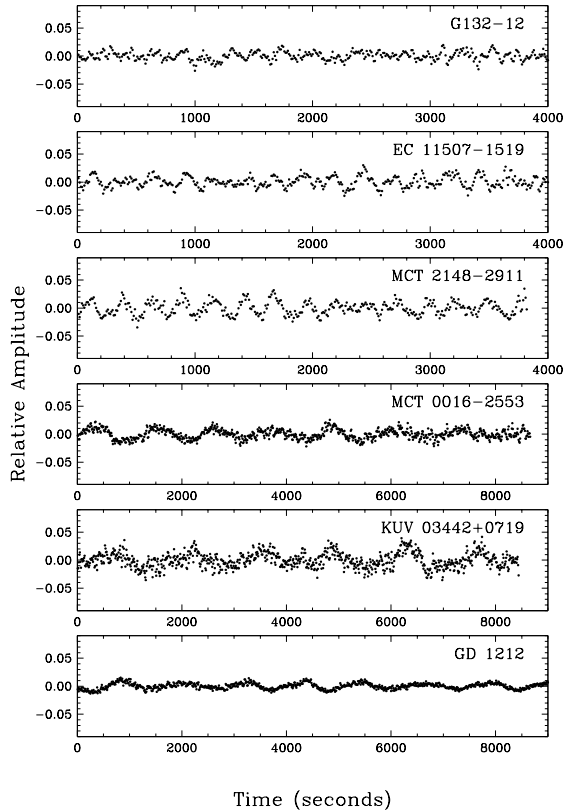


FIG. 1.— Light curves of the 6 new ZZ Ceti stars observed in “white” light by LAPOUNE at Steward Observatory’s 2.3 m telescope with the exception of MCT 2148–2911 that was observed with LAPOUNE attached to the 3.6 m Canada-France-Hawaii telescope through a B-band filter. Each point represents a sampling time of 10 s. The light curves are expressed in terms of residual amplitude relative to the mean brightness of the star.

to be variable, this criterion was not met for the three longer period variables. It will therefore be necessary to acquire new optical spectra for these stars in order to refine our determination of their atmospheric parameters. Consequently, the atmospheric parameters for these objects are considered preliminary and as such, they are marked with a colon in Table 4. Nonetheless, these results demonstrate once again the ability of the spectroscopic method, pioneered by Bergeron et al. (1995), at predicting the variability of DA white dwarfs.

TABLE 3
PHOTOMETRICALLY CONSTANT DA WHITE DWARFS

WD	Name	V	Detection limit (%)
0136+768	GD 420	14.85	0.13
0145+234	MK 362	14.50 ^a	0.06
0302+621	GD 426	14.95	0.19
0347-137	GD 51	14.00 ^a	0.15
0416+701	GD 429	14.74	0.07
0741+248	LP 366-3	16.52	0.34
1211+320	CBS 54	16.00 ^a	0.54
1503-093	EC 15036-0918	15.15	0.27
1820+709	GD 530	17.00	0.56
2311+552	GD 556	16.17	0.15

^aPhotographic B magnitudes.

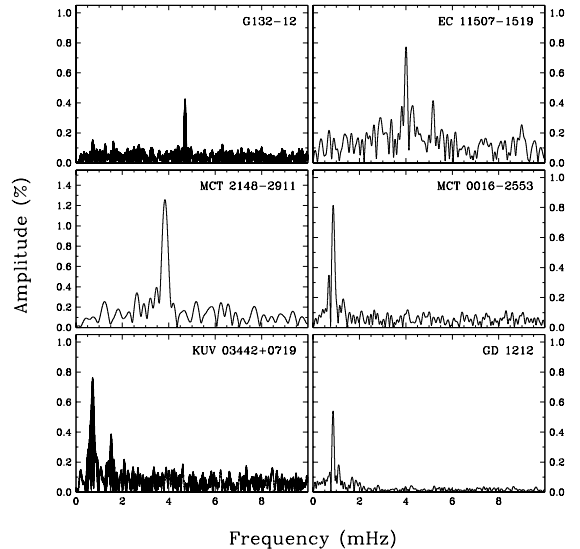


FIG. 2.— Fourier (amplitude) spectra for the light curves of the 6 new ZZ Ceti stars in the 0–10 mHz bandpass. The spectrum in the region from 10 mHz to the Nyquist frequency is entirely consistent with noise and is not shown. The amplitude scales are identical for each star for the purpose of comparison with the exception of MCT 2148–2911 due to its larger amplitude. The amplitude axis is expressed in terms of the percentage variations about the mean brightness of the star.

Our updated ZZ Ceti instability strip is displayed in Figure 3 together with the empirical blue and red edges allowed by our current atmospheric parameter determinations for these stars. Note that three low-gravity objects, shown by filled squares in Figure 3, represent unresolved double degenerate systems and that the atmospheric parameters are the average values of both components of the system; the red square is GD 429 (WD 0416+701) identified as a velocity variable by Maxted et al. (2000). Hence these cannot be used to constrain the slope of the blue edge, as discussed by Gianninas et al. (2005). Furthermore, since the atmospheric parameters for the new long period variables are preliminary, we have refrained from redefining the empirical red edge, and we have simply reproduced in Figure 3 the value obtained by Gianninas et al. (2005). It is clear that additional observations are required to pin down the final empirical boundaries, in particular near the blue edge of the strip. Hopefully we will report such observations in the near future when our survey is completed.

We note that the periods of the dominant oscillation modes in the first three stars of Table 2, as well as those of the last three objects, are consistent with the positions of these stars inside or near the blue (short-period pulsators) and red (long-period pulsators) edges of the instability strip, respectively. However, as a curiosity, we also point out that the amplitudes of the detected modes in the three “red edge” pulsators are not very large, especially for GD 1212. This goes against the general tendency to observe large amplitudes in the cooler objects. Note also the very long period seen in KUV 03442+0719, one of the longest if not the longest one ever detected in a ZZ Ceti star. Are we observing stars at the very red edge of the strip, basically “dying off” in amplitude?

Finally, during the 2005 October observation run, the

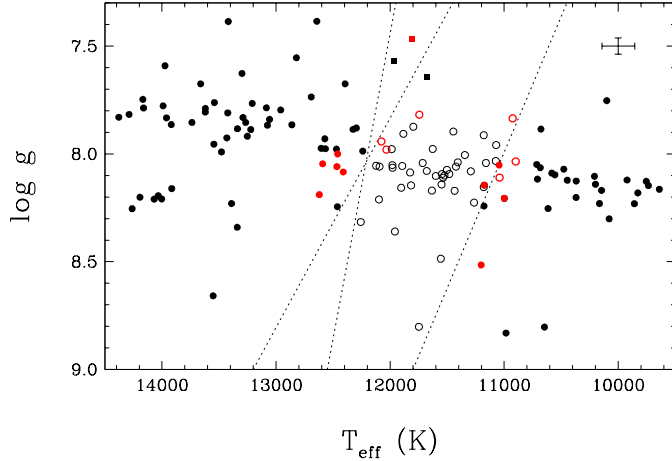


FIG. 3.— $T_{\text{eff}} - \log g$ distribution for DA white dwarfs with high-speed photometric measurements. The black open and filled circles represent respectively the 39 ZZ Ceti stars and the 121 constant DA stars taken from Gianninas et al. (2005, and references therein), while the red open and filled circles represent the 6 new ZZ Ceti stars and the 10 constant DA stars reported in Tables 2 and 3, respectively. The filled squares correspond to unresolved double degenerate systems (see text). The error bars in the upper right corner represent the average uncertainties of the spectroscopic method in the region of the ZZ Ceti stars (1.2% in T_{eff} and 0.038 dex in $\log g$). The dashed lines represent the empirical blue and red edges of the instability strip allowed by our current atmospheric parameter determinations for these stars.

TABLE 4
ATMOSPHERIC PARAMETERS OF NEW ZZ CETI AND
PHOTOMETRICALLY CONSTANT DA STARS

WD	Name	T_{eff} (K)	$\log g$	M/M_{\odot}	M_V
ZZ Ceti					
0016–258	MCT 0016–2553	10900:	8.04:	0.63	11.92
0036+312	G132-12	12080	7.94	0.57	11.53
0344+073	KUV 03442+0719	10930:	7.84:	0.51	11.62
1150–153	EC 11507–1519	12030	7.98	0.60	11.59
2148–291	MCT 2148–2911	11740	7.82	0.51	11.42
2336–079	GD 1212	11040:	8.11:	0.67	11.99
Photometrically Constant					
0136+768	GD 420	11050	8.05	0.64	11.90
0145+234	MK 362	12470	8.06	0.64	11.64
0302+621	GD 426	11000	8.21	0.73	12.15
0347–137	GD 51	12620	8.19	0.72	11.81
0416+701	GD 429	11810	7.47	0.35	10.94
0741+248	LP 366-3	12410	8.08	0.66	11.69
1211+320	CBS 54	12460	8.00	0.61	11.56
1503–093	EC 15036–0918	12590	8.05	0.64	11.61
1820+709	GD 530	11200	8.52	0.94	12.61
2311+552	GD 556	11180	8.15	0.69	12.01

observing conditions were such that we were also able to revisit G232-38 whose discovery as a ZZ Ceti star was reported in Gianninas et al. (2005). Indeed, the discovery light curve (see Fig. 2 of Gianninas et al. 2005) had been obtained with LAPOUNE attached to the 1.6 m telescope of the Observatoire du mont Mégantic under less than ideal conditions. Having a 2.3 m telescope at our disposal, we were certain we could achieve a better

result. The new light curve we obtained, which is just over 3 hrs long (see Table 1), is shown in Figure 4.

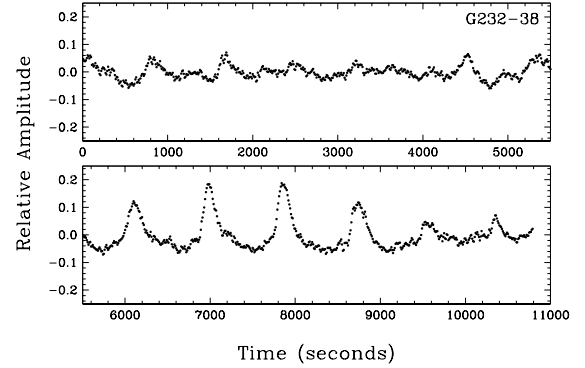


FIG. 4.— Same as Fig. 1, but for G232-38.

On inspection, we see that this new observation is indeed much better than the previous one with the pulsations very clearly visible. The amplitude modulation due to destructive interference between the different pulsation modes is also very evident. From this light curve, we computed the Fourier (amplitude) spectrum shown in the top panel of Figure 5. The dominant pulsation period obtained from the Fourier spectrum is 870.4 s. The light curve and associated Fourier spectrum are, in fact, quite reminiscent of those found in another cool large amplitude ZZ Ceti star, GD 154 (Pfeiffer et al. 1996) whose Fourier spectrum is shown in the bottom panel of Figure 5. The Fourier spectrum of GD 154 was calculated from a nearly 6-hour long light curve which we obtained on the night of 1991 May 22 with LAPOUNE attached to the 3.6 m Canada-France-Hawaii telescope. It is likely, as in GD 154, that the main peak in the Fourier spectrum of G232-38 contains a few closely spaced modes in frequency, and that the other peaks are simply nonlinear structures caused by harmonics and cross-frequencies of

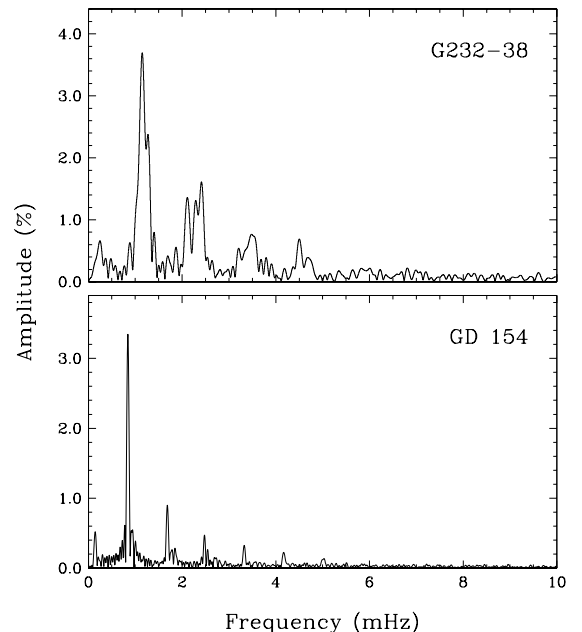


FIG. 5.— Same as Fig. 2, but for G232-38 (top) and GD 154 (bottom).

the main modes.

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